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Estimating the Role of Spatial Varietal Diversity on Crop Productivity within an Abatement Framework

The Case of Banana in Uganda

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Contents

List of Tables

ABSTRACT

Increasingly, research has indicated that in more risky production environments, genetic variation within species and within population increases the ability to respond to the increasing challenges of environmental stress. This paper analyses the role of banana variety diversity in reducing yield losses associated with biophysical production constraints in Uganda. A damage abatement framework is applied to enable estimation of the contribution of both direct and indirect inputs to the banana yield per unit of area. Primary data were gathered from 120 households. Results indicate that banana variety diversity contributes positively to reducing yield losses caused by biophysical constraints, particularly pests and diseases, but trade-offs exist. High banana variety diversity also has a significant but negative direct impact on banana yields. These trade-offs imply that while banana variety diversity should be promoted for its risk-reducing effects, its adoption beyond what farmers are practicing will largely depend on their objectives, access to alternative abatement agents, and their ability to bear risk. Given the current banana production environment of limited abatement agents and high biotic stress, enhancing diversity appears to be an important option despite trade-offs.

Keywords: banana diversity, direct inputs, indirect/ damage abatement inputs

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1. INTRODUCTION

Crop diversity has various values for farmers. In less-favored environments, where crop production is risky and opportunities for off-farm work are limited, crop diversity is often a response to risk by farmers. In Uganda, banana variety diversity is high at country, farm, and plot levels. At the country level, a total of 95 banana varieties are currently grown (Karamura 1998). A typical household grows an average of 7 banana varieties simultaneously in the same plot, but the number can go as high as 27 on some farms (Tushmereirwe et al. 2003). Some studies have attributed high banana variety diversity to the diverse ways the crop is used (for example, in main dishes, beer, and desserts) and consumer preferences (Nowakunda et al. 2001). In a different study, Edmeades, Smale, and Karamura (2006) reveal that production traits are also important in explaining high banana diversity and maintaining cultivar diversity could be a deliberate strategy by farmers to manage abiotic and biotic stresses.

There is increasing evidence that high genetic variability within and between species confers the potential to resist biotic and abiotic stresses, both in the short and long terms (Giller et al. 1997). Empirical findings on the effect of diversity on crop productivity have been mixed. For example, Smale et al. (1998) modeled diversity as a component of the constant in a Cobb-Douglas production function and found that allocating more area to fewer varieties increased mean yield of wheat in Punjab for the period under consideration. Di Falco, Chavas, and Smale (2007) reported a positive relationship between variety richness and farm productivity. Most of the empirical studies, however, have treated diversity as a direct variable that shifts the yield function. By treating diversity as a direct input, these studies failed to isolate the abatement effects of diversity from its yield-enhancing effects. Furthermore, the impact of crop diversity on crop productivity has mostly been observed on annual crops; little has been done on perennial crops. Yet, perennial crops are fundamentally different from annual crops regarding pest and disease damage pressure. In annual crops, pests and diseases may be starved out during fallow periods or when crop rotation is used. Thus the spread of pests and diseases can be easily blocked by crop variety diversity. Perennial crops, on the other hand, are permanent, and this implies that the capacity of crop variety diversity to continuously block the spread can easily break down.

This paper contributes to the growing literature on the value of crop variety diversity by applying an abatement framework. It analyzes the impact of spatial variety diversity on the yield of banana, a perennial crop highly susceptible to pests and diseases. Two pests (nematodes and banana weevil) and four diseases (black sigatoka, fusarium wilt, banana bacterial wilt, and banana streak virus) are prevalent in Uganda, which makes this study relevant for testing the role of diversity on reducing yield loss associated with pests and diseases in perennial crops. The study was implemented within the framework of the global project "Conservation and Use of Crop Genetic Diversity to Control Pests and Diseases in Support of Sustainable Agriculture." The project was coordinated by Bioversity International and supported by the Global Environment Facility (GEF) and the United Nations Environment Programme (UNEP) in four countries: China, Ecuador, Morocco, and Uganda. It included six crops: maize, barley, beans, faba beans, rice, and banana/plantain. The project aimed at conserving crop genetic diversity in ways that increase food security and improve ecosystem health. It also aimed at enhancing conservation and use of crop genetic diversity by farmers, farmer communities, and local and national institutions to minimize pest and disease damage on farm. Being part of the larger project makes it possible to compare these findings with results from other countries, in particular Ecuador, where banana is also a target crop.

This study was carried out in two districts of Uganda—Bushenyi and Nakaseke. Bushenyi District is one of the leading banana-producing areas, with many organized and well-managed banana farms. Banana is a semisubsistence crop sold both in the domestic market and to the neighboring countries. Nakaseke District is located in an area of low elevation, where banana productivity has severely declined. Banana cropping patterns and systems in Nakaseke are distinct from those of Bushenyi. In Nakaseke, the scale of production is smaller and banana is grown under intensive intercropping, compared with Bushenyi District. Banana intercrops range from annual crops to agroforestry, especially fruit trees. Pests and diseases are a common problem of bananas in Uganda and these problems have been prevalent in both Nakaseke and Bushenyi for approximately the same period of time. Nevertheless, banana yields in Bushenyi are significantly higher than yields in Nakaseke, due to the high production potential in Bushenyi. Banana production in both sites thrives on family labor, with both male and female members of the households involved in providing this labor**.**

2. CONCEPTUAL FRAMEWORK

In this study we use the damage abatement framework developed by Litchenberg and Zilberman (1986) to estimate the effect of banana diversity on banana production and on the control of pests and diseases. This framework is based on the idea that some agricultural inputs such as insecticides are not yield-enhancing, but they abate yield losses. The damage abatement effect is defined as the proportion of the destructive capacity of the damaging agent that is eliminated by applying a certain amount of a control input. Control inputs could be pesticides, labor, cultural practices, a crop variety, or any other input that the farmer uses with the intention of mitigating the impact of pests and diseases (Oude Lansink and Carpentier 2001).

Guan et al. (2005) proposed a broader characterization of the inputs. The first category of "growth" inputs is directly involved in the biological and agronomic processes of crop growth. The second group, termed "facilitating inputs," is used to help create favorable growth conditions (Zhenfei et al. 20005). Both Lichtenberg and Zilberman (1986) and Guan et al. (2005) recognize that if all inputs intended to control damage are treated as growth or facilitating inputs, then their effects on production will likely be overestimated. The approaches they propose are suitable for estimating the effect of inputs on yield, as well as the interaction effects among inputs.

The contribution of banana variety diversity to banana yield can be explained either directly as increasing yield due to a sampling effect (Fargione and Tilman 2005) or as a damage abatement input due to complementarity effects (Loreau and Hector 2001). In the sampling effect, growing more diverse crop species (in this case bananas) may increase the probability of growing the best adapted species, while the complementarity effect implies that different crop species (bananas) have a broader range of traits and characteristics and can perform under different biophysical conditions. For example, research on rice done by Youyong et al. (2000) in China indicates that rice blast—a major disease in rice—was 94 percent less severe when susceptible rice varieties were grown together, rather than in monocultures.

Based on the literature and the production theory, the role of diversity in banana production can be specified as

$$Y = f(X, G(Z), \varepsilon) \quad , \tag{1}$$

where Y is the banana output per acre and X_is are the vectors of variables representing controllable inputs that facilitate the realization of Y through their involvement in the biological and agronomic processes of banana growth. Z represents the vector of controllable inputs that abate the destructive capacity of pests and diseases, thus creating a favorable environment for banana growth while G (.) if the abatement functions. ε is a vector of non controllable inputs (such as weather conditions Banana production in Uganda involves application of a wide range of management practices with labor as the main input. Some of these management practices contribute directly to increase yield, some contribute indirectly through abatement effects, and others contribute through both mechanisms. Management practices considered to contribute directly to yield are mulching, manure application, desuckering, and stumping. Management practices like corm paring, detrashing, splitting pseudo stems, corm removal, and corm cover contribute to yield both directly and indirectly. Mulching is a practice whereby dry organic materials are spread between the banana mats (i.e. banana plants rooted from the same corm) to suppress weed growth, conserve soil moisture, and add nutrients to the soil. Corm paring is the removal of the outer sheath from the corm of a sucker before planting to avoid transfer of pests/ or diseases into new plots. Detrashing is the removal of the dry leaves and the sheath from banana plants. Desuckering is the removal of excess plants from a mat. Stumping, corm removal, splitting, or chopping pseudo stems are residue management practices carried out in bananas after harvest to maintain sanitation in the plantation. Weevil trapping is a pest control techniques that in which weevils (the pest) are physically trapped and killed to reduce their infestation and damage.

On the sampled farms, weevil trapping was the only management practice that exclusively has an abatement effect in banana production. Here x is used as a subset of X to denote controllable inputs that play dual roles and hence should be included in the production function both as facilitating inputs and indirectly as abatement functions. Labor expenditures with respect to management practices to control pests and diseases and diversity are contained in *x,* while variables with only an abatement effect are in *Z*.

$$Y = f[X, G(x, Z), \varepsilon] \tag{2}$$

In the damage abatement, productivity of damage control inputs is defined in terms of their contribution to damage abatement services. Their productivity can be no larger than the destructive capacity of the pest and is also limited by the maximum potential output. Hence, *G (x, Z)* takes the values defined on the 0, 1 interval with *G* = 1 denoting complete eradication of the destructive capacity of the damage agent and *G* = 0 denoting zero elimination. In other words, If *G(x, Z)* = 0, that implies that there is no control of the damage and *Y* = *F (X, 0)*. If *G(x, Z)* = 1, that means that there is complete control and therefore *Y* = *F (X,* 1). The functional specification of *G* (**.**) admits the possibility of the positive output level with zero *Z* usage (Saha, Shumway, and Havenner 1997). This is important for estimating the effect of the inputs that are used to reduce potential losses caused by damage, that is, *Y* = *F[X, g*(0)] > 0 is feasible.

Note that *F(X)* can take different functional forms. The most commonly used specification is the Cobb-Douglas function, but it shows some constraints for the estimation of the model. Under this specification the explanatory variables cannot take values of zero. Nonlinear functional forms are used as the more solid functional forms.

3. EMPIRICAL DEFINITION OF VARIABLES IN THE MODEL

3.1. Dependent Variable Definition

The dependent variable *Y* is defined as banana yield per acre obtained during the production period of six months. Banana in Uganda is usually harvested piecemeal (one bunch at a time) and measuring yield presents one of the challenges in banana research. Being a perennial crop, yield observed in a period of six months is a result of the cumulative effect of input use. However, it is assumed that this reflects the past input use and hence approximates what happens in practice. Banana yield is estimated as a product of banana bunch size in kilograms (kg) and the number of bunches harvested per acre. This definition aggregates yield across all the varieties grown in the plot. The banana yield in this study was measured in the plot identified as the major banana plot by the farmer.

Farmers over time have learned to classify banana bunches as small, medium, and large. Respondents were asked to estimate the number of small, medium, and large bunches that were harvested in the plots over a period of six months and helped to estimate the different bunch weight categories using standard local measures (different volumes of water jerricans) equivalent to 5, 10, 20, and 40 kg weights. The yield obtained from the major banana plot was standardized to per acre and was calculated as

$$\text{Yield} = \sum_{t=i}^{n} b_t n_t, \tag{3}$$

where b_t is the average size of the banana bunches obtained on the major banana plot and n_t is the number of bunches harvested in a period of six months. The unit used for banana yield in this study is kg/acre, and from the descriptive statistics, the mean yield of banana was 3,632 kg/acre in Kabwohe and 2,026.39 kg/acre in Nakaseke (Table 1). Yield values in the models were converted into logs.

Table 1. Descriptive statistics of the sample

Characteristic	Nakaseke	Kabwohe	Overall
Years of formal education attained by the household head	6.63	6.37	6.50
Total land (acres) owned by the household	6.14**	3.11**	4.64
Total land (acres) allocated to banana production	0.94***	1.67***	1.30
Average number of banana mats in banana plots	168.38***	489.46***	327.57
Average number of banana varieties in banana plots	7.90***	5.68***	6.80
Yield of bananas in kg/acre	2,026.39***	3,632.34***	2,815.75
Proportion of bananas sold(%)	14.25***	35.33***	24.71
Number of crops intercropped with bananas	1.88**	1.46**	1.67
Farmers who have experienced banana sigatoka (%)	88.33***	38.98***	63.87
Farmers who have experienced nematodes (%)	52.54*	69.49*	61.02
Farmers who have experienced fusarium wilt (%)	86.67***	27.12***	57.14
Years of fusarium wilt	3.26	4.65	3.6
Years of sigatoka	5.47	6.38	5.74
Years of nematodes	7.30	7.61	7.47
Loss in yield in bananas caused by black sigatoka (%)	27.35***	14.76***	21.11
Loss in yield in bananas caused by nematodes (%)	18.49	18.74	18.62

Source: Primary data.
Note: Significance levels are denoted by one asterisk (*) at the 10 % level, two asterisks (**) at the 5 % level, three asterisks (***) at the 1 percent level.

3.2. Explanatory Variables

The explanatory variables, descriptive statistics, and their hypothesized effects are presented in Table 2. The explanatory variables included in the model were derived from the conceptual framework, existing information about banana production in Uganda, and review of literature.

Table 2. Explanatory variables in the yield models and their hypothesized effects

Variable		Definition	Expected effect	Mean	Standard deviation
Damage abatement Inputs	Herfindahl index	Measure of spatial banana diversity	+	0.34	0.15
	Banana evenness	Proportion occupied by the major banana variety in the plot (%)	+	0.47	0.16
	Banana richness	Number of banana varieties in the plot	+	5.97	2.64
	Number of banana intercrops	Number of banana intercrops	+ /-	1.67	0.77
	Family labor used to control pests and diseases	Family labor (expressed as a natural log) used to control banana pests and diseases measured in man hours	+	97.43	190.20
Facilitating inputs	Family labor used as direct input	Family labor (expressed as a natural log) used as direct input and measured in man hours	+	401.52	880
	Other inputs dummy	A dummy for other inputs – use of organic fertilizers (1=Yes, 0= No)	+		
	Banana richness	Number of banana varieties in the plot	+	5.97	2.64
	Banana evenness	Proportion occupied by the major banana variety in the plot (%)	+	0.47	0.16
	Herfindahl index	Measure of spatial banana diversity that combines richness and evenness aspects of diversity	+	0.34	0.15
Other explanatory variables	Age of the household head	Age (years) of the household head	+	49.13	14.26
	Education of the household head	Number of years spent in school by the household head	+	6.5	4.11
	District dummy	Location of the study site (1- Kabwohe, 0- Nakaseke)	+	1.5	
	Value of livestock	Total value (Ugandan Shillings: Ushs) of all livestock owned by the household	-	1,372,908	7,613,107
	Number of banana mats	Count of the banana mats in the major banana plot	+/ -	259.88	343.96
	Slope	A dummy capturing the physical orientation of the banana plot (1=flat, 0= Otherwise)	+	0.18	

Source: Primary data.

Banana diversity was measured using a normalized Herfindahl index, also known as the Herfindahl-Hirschman index. This is a continuous index with values ranging between zero and one. The Herfindahl index is preferred in this study as a measure of genetic diversity because it is simple to construct and yet elaborate enough to describe both richness and evenness. The value of one indicates that all area is planted to a single variety, and a very small value tending to zero indicates that a large number of each of the varieties is planted to a very small area. The normalized index is computed by subtracting $1/N$ from the numerator and denominator of the usual Herfindahl index, as in Owen, Ryan, and Weatherston (2006):

$$H^* = \frac{(H - 1/N)}{1 - 1/N} \tag{4}$$

where H^* is the normalized Herfindahl index; H is the usual Herfindahl index, which varies between $1/N$ and unity; and N is the number of counted banana varieties in the banana major plot identified by the farmer. The usual Herfindahl index is given by

$$H = \sum_{i=1}^{N} S_i^2$$

where S_i is the mat share of variety i in the main plot composed of N different varieties. To generate the index values, the number of banana mats of each variety was counted to estimate the proportion occupied by each variety that is planted. The information was collected from the plot that farmers identified as the major banana plot. Separate measures of diversity (evenness and richness) are also included. Evenness is measured as the proportion occupied by the major banana variety in the major banana plot and ranges from 0 to 1, while richness is measured as the different number of banana varieties in the plot.

The variable intercrop captures the effect of intercropping intensity in banana plots on banana yield. The effect of other intercrops on banana yields work through various mechanisms that can be contradictory and cannot be determined a priori. For example, some intercrop(s) such as beans act as an alternative host to pests or diseases that affect banana (Namaganda 1996) and have soil amendment benefits that could benefit the banana crop.

Labor is perhaps one of the most important inputs in banana production in Uganda. Part of labor is used to implement a range of banana management practices with only direct effects (such as mulching, manure application, desuckering, and stamping),while some of the labor is used to implement management practices that only influence yield indirectly through an abatement effect (for example, weevil trapping). Much of the labor, however, is used to implement management practices (corm paring, detrashing, splitting pseudo stems, weevil trapping, corm removal, and corm cover) that have both direct and indirect effects. Labor is disaggregated according to the category of management practices implemented and included in the model accordingly.

Labor spent on implementing all banana management practices, except weevil trapping, is included in the model as a facilitating (direct input). But labor expenditure on corm paring, detrashing, splitting pseudo stems, weevil trapping, corm removal, and corm cover is treated as an abatement input. Labor is obtained as the product of the number of days worked and the hours used on each banana management activity by family members (men, women, and children). This is an appropriate measure of total labor used since family labor is the main source of labor used in banana production in Uganda. The labor hours used on each banana management activity is then computed for a period of six months.

The amount of fertilizer is another facilitating variable in banana production. Rarely do Ugandan farmers use inorganic fertilizer in banana production, and very few farmers in the sample used organic fertilizers in the form of mulch or manure. Due to the very few positive uses, a dummy variable that captures farmers who use organic fertilizers is used.

Banana diversity is included in the analysis as both a direct input and as a damage abatement input. As a direct input, the role of varietal diversity is unclear. Different crop varieties have different genetic makeups, which implies different yielding potential. Mixtures may decrease the spatial density of genetically high yielding varieties, thereby decreasing yield potential per unit area. As a damage abatement input, diversity provides a barrier effect whereby resistant plants fill the space between susceptible components (Finckh and Wolfe 1997).

Other variables included as yield shifters are age and education of the household head, livestock value, scale of production, slope of the plot, and use of other inputs (Table 2). According to economic theory, experience increases technical efficiency and age is used as a proxy for experience in managing banana plantations. Education is also an important variable. We hypothesize that respondents who have attained higher levels of education obtain higher banana yields because they have better access to information and hence better management skills. The value of livestock in the household is also included as an explanatory variable. We expect that higher livestock value is highly correlated with more access to manure, which is commonly applied to the banana plots.

The scale of production represented by the number of banana mats is also included as an explanatory variable, but its effects on yield cannot be predicted a priori. The number of banana mats is preferred over the acreage occupied by bananas, since it is easier to measure and hence carries less measurement error. The slope of the plot is represented for a dummy measured as one when the plot is flat and zero otherwise. Farmers with banana plots on flat slopes are expected to obtain higher yields because flat slopes suffer less erosion from running water than steep slopes. Finally, a dummy measured as one when the household is located in Kabwohe and zero when it is in Nakaseke is included in the model to control for district effects.

3.3. Data Sources and Sample Design

Data for the study was collected from individual household surveys, using a pretested questionnaire. One subcounty was selected from each district: Nakaseke subcounty from Nakaseke District and Kabwohe from Bushenyi District. These subcounties were already selected for a large project on "Conservation and Use of Crop Genetic Diversity to Control Pests and Diseases in Support of Sustainable Agriculture," to which this study contributes. In each subcounty, two parishes that were previously used as study sites for the main project were purposively selected, and in each parish, two villages were randomly selected. A systematic random sampling with a random start was employed to select the sample from the compiled lists of households provided by the village leader. Sixty respondents were obtained from each subcounty. The sample size was predefined by the project.

The descriptive statistics for the selected sample characteristics are presented in Table 1. At both study sites, the average education level of farmers is low, estimated at six years of schooling, and landholding sizes have been diminishing but more so in Kabwohe than in Nakaseke. Consequently, the intensity of land use in terms of cropped area is higher in Kabwohe (90.39 percent) than in Nakaseke (79.87 percent). There are more female-headed households in Nakaseke than in Kabwohe. Earlier studies (for example, Edmeades, Smale, and Karamura 2006); on banana production in similar regions report similar statistics for household headship, education, landholding, and diversity of varieties, which validates the data used in this paper.

On average, each household maintains about one acre of land under bananas, planted to about 300 banana mats and a few intercrops. Consistent with the earlier studies, banana yield in terms of bunch size and in kgs/acre is significantly higher in Kabwohe (found in western Uganda) than in Nakaseke (located in central Uganda (Table 1). Farmers in Kabwohe are also more commercially oriented, selling about 35 percent of their harvest. They also use more inputs such as organic fertilizers (cow dung) than their counterparts in Nakaseke.

Generally, most farmers (55.46 percent) in both areas farm as the primary source of livelihood, implying that managing risk ex ante will contribute greatly to the livelihoods of poor people. Banana yields have been on the decline in both central and southwestern Uganda. This has been attributed to pests and diseases, decline in soil fertility, and reduced banana management, especially in central Uganda (Tushmereirwe 2003). Of the prevalent banana production biophysical constraints mentioned in section 1, fusarium wilt, black sigatoka, and nematodes are important in the study area. Fusarium wilt and black sigatoka diseases are more prevalent in Nakaseke (reported by 86 percent of the farmers) than in Kabwohe (reported by less than 40 percent of the farmers. Both locations have experienced the problem of nematodes, but the farms in Kabwohe have been hit significantly harder by the pest than the farms in Nakaseke. Aggregately, more than 60 percent of farmers experience at least one of these constraints, causing about 20 percent yield loss.

In the study sample, banana variety diversity is as high as the national average but slightly higher in Nakaseke and lower in Kabwohe. The average number of banana varieties grown on Nakaseke farms is 8 varieties, compared with 6 in Kabwohe, with some farmers having as many as 23 varieties in Nakaseke, compared with a maximum of 13 varieties on Kabwohe farms.

4. ECONOMETRIC ESTIMATION

Nonlinear models are usually employed to obtain the effect of the explanatory variables on the dependent variable. There are various ways to model abatement function, but three econometric estimations are commonly used. These are

- exponential function: $G(X) = 1 - e^{-\lambda(x,Z)}$,
- logistic function: $G(x, Z) = 1 + \exp[\mu\text{-}\ \sigma(x,Z)]^{-1})$, or
- Weibull function: $G(x,Z) = 1 - \exp\,[-\lambda(x,Z)]$.

In all forms, $G(Z)$ is unobservable, but the control agent (Z) can be directly estimated. The units used to express Z can vary depending on the type of input.

Generally, results from the abatement framework are very sensitive to the specification form of the damage control function. There is no agreement in the literature on the most suitable specification form of the damage control function (Carrasco-Tauber and Moffitt 2009) ; Fox and Weersink 1995; Pemsl 2005. Because of this, some authors use the information criterion (AIC) as suggested by Akaike (1973) to obtain the best model (Carrasco-Tauber and Moffitt 2009; Saha et al. 1997) or the specification whose results in terms of significance, magnitude, and direction better explains the relationship (Huang et al. 2002). Data were tested on all of the three econometric specifications listed above, and the logistic specification gave more stable results that better explain the relationship between yield and the exogenous variables; hence it was used.

When the decision to include various banana varieties in the plot is motivated by the need to increase yield, diversity is endogenous in the model. Endogeneity of diversity entails a potential correlation between inputs and the error term, which renders inconsistent estimates. Therefore, a Durbin-Wu-Hausman statistic described in (Wooldridge 2002) is performed to test for endogeneity of diversity in the yield equation. This is done in two steps. In the first step, the banana diversity index is regressed on all exogenous variables in the model and instrumental variables. In the second step, the resultant residues from the first regression are included in the banana yield model as an additional regressor.

5. RESULTS AND DISCUSSION

Since the endogeneity test (Table 3) does not support the possibility of endogeneity (the residual of the Herfindahl index is insignificant), diversity is included directly in the nonlinear yield models.

Table 3. Testing for endogeneity of banana intraspecific diversity in the banana yield equation

Explanatory variable	First step estimation results of diversity use		Second step estimation results of yield (ln kg/acre)	
	Coefficient	t-statistic	Coefficient	t-statistic
Constant	0.434	5.08***	5.26	1.74**
Herfindahl index			-0.30	-0.38
Residue of Herfindahl index			0.664	0.11
District dummy	**-0.054**	**-1.93****	**0.36**	**0.68**
Gender	0.071	1.98**	.094	.19
Decisionmaking (dummy)	.087	2.79***	-0.14	-0.22
Education of the household head	-0.002	-0.57	0.018	0.67
Value of livestock	-8.6^-10	-0.49	1.19^-8	0.78
Family labor used as a direct input	-2.6^-5	-1.77*	0.29	2.6*
Number of banana mats	4.2^-5	0.88	-0.0008	1.94*
Farmer perception about yield loss in bananas due to nematodes (%)	-0.015	-2.08**		
Slope dummy (flat)	0.007	-0.18	0.86	2.82***
Number of banana intercrops	-0.016	-0.95	0.27	1.63
Distance to tarmac road	-0.005	-1.7*	-0.026	-0.59
Time to town	0.00124	0.63	-0.021	-1.18

Source: Authors' estimations.
Notes: Number of observations = 119.
First step: Prob>F = 0.045; Adj. R^2=0.15; Second step: Prob>F = 0.000, Adj. R^2=0.29.

Results obtained from the damage abatement model using the logistic specifications are presented in Table 4. Model 1 shows results of spatial variety diversity that combines both richness and evenness, while model 2 separates the effect of richness and evenness on yield. In both models, the adjusted R^2 is high (98 percent), implying that the variation in yields is well explained by the exogenous variables.

Table 4. Estimates of the effect of banana intraspecific diversity and other factors on banana yields

Explanatory variable	Model 1		Model 2	
	Logistic (Herfindahl index)		Logistic (evenness and richness separate)	
	Coefficient	t- value	Coefficient	t-value
Number of varieties			0.07	0.86
Share of major variety			5.14	6.8***
Herfindahl index	4.89	4.12***		
District (dummy)	0.82	3.08***	0.834	3.1***
Age of household head	0.023	2.89**	0.21	2.71***
Education of household head	0.05	1.9*	0.05	1.82*
Total livestock	$8.29x10^{-9}$	0.56	$8.12x10^{-9}$	0.56
Total number of mats	.0006	1.56	.0005	1.4
Number of banana intercrop	0.81	3.38***	0.47	1.72*
Slope dummy (flat),	0.84	2.67***	0.82	2.69**
Family labor used as a direct input	0.65	4.87***	0.52	4.1***
α (Costant)	-4.45	-1.89**	-8.1	-1.72*
β (Herfindahl index)	-7.12	-1.92*		
γ (Intercropping)	-0.765	-1.34	-0.22	-0.39
λ (labor to control pests and diseases)	-0.0005	-0.88	-0.0001	-0.21
Δ (number of different varieties)			-0.22	-0.98
Ø(share of the major banana variety)			-12.1	-2.07**
	Observations =119		Observations =119	
	Adj. R^2 = 0.976		Adj. R^2 = 0.98	

Source: Authors' estimation.
Notes: A positive sign in the abatement implies that the variable in question reduces the yield loss caused by biophysical constraints. The interpretation of the sign on the Herfindahl index variable is the opposite since, by construction, an index value close to 1 indicates very low diversity while the value close to zero indicates very high banana diversity. Significance levels are denoted by one asterisk (*) at the 10 % level, two asterisks (**) at the 5 % level, three asterisks (***) at the 1 percent level.

Results of model 1 show that the variety diversity (presented as the Herfindahl index) has a negative direct effect on yield but a significant (P>0.05) and positive damage abatement effect (Table 4). In other words, although banana variety diversity does not contribute directly to increasing banana yield, it reduces the yield losses caused by biophysical pressures. Notice that by construction, a lower index value implies a higher banana intraspecific diversity. Other studies (Burdon 1987; Burdon and Jarosz 1989) have found out that diversity helps in decreasing the spatial density of susceptible plants. Likewise, diversity in banana production provides a barrier effect where resistant plants fill the space between susceptible components.

Important results also emerge from the estimation of model 2 (Table 4). When a major variety has a bigger share in the plot, overall banana yields are significantly higher, but the effect of abating damage caused by biophysical pressures is significantly reduced. A negative relationship between variety diversity and yield at plot level has also been observed in other studies (van Dussen 2006; Winters et al. 2006). Farmers who aim at maximizing profits tend to choose a few varieties that are high yielding and marketable (Winters et al. 2006). On the other hand, the number of banana varieties, a measure of diversity richness, has no significant effect either in increasing yields or reducing the yield losses caused by biophysical pressures. It thus appears that what is important in abating damage in bananas is diversity evenness in the plot—not how many varieties are in the plot. This is an important result since it tells which aspect of diversity is important in reducing yield loss.

Results of both models indicate that intercropping has no significant effect in reducing yield losses in bananas, but it does have a significant effect as a yield-enhancing variable. The direct effect could be associated with the soil fertility amendment effect from some intercrops, such as legumes (Akuja et al. 2003). This result should, however, be interpreted with caution since only counts of crops were used in the analysis, and trees that were scattered in the plots were not included as intercrops. A more detailed study for the effect of interspecific crop diversity on banana yield would be necessary to better explain the relationship.

The models also show no evidence that an increase in labor applied in banana plantations to reduce pests and diseases is significant in reducing the yield losses caused by biophysical pressures. As implied from earlier studies (Kalyebara et al. 2007) finding that banana management practices alone cannot address the pest and disease problems, the result may be interpreted to mean that labor inputs are not sufficient to show a significant impact on yield loss abatement. Household characteristics also provide an important explanation for variations in yield across households. Older household heads obtain higher banana yields than younger household heads. Age is associated with experience in banana management. Older household heads are more experienced and hence technically more efficient in managing the banana plantations than the younger household heads. Education is found to be significant ($P>0.1$) in influencing yield. This is because education also increases technical efficiency through acquisition of knowledge and perceiving and processing information (Schultz 1975). Educated farmers can thus easily develop better management skills, resulting in an increase in banana yields.

Finally, results show that yields tend to be higher in plots established on flatter slopes. This is because water and soil nutrient loss tend to be relatively lower on flat land than on steep slopes due to reduced water runoff.

6. CONCLUSION AND POLICY IMPLICATIONS

6.1. Conclusion

This study, derived from the existing literature, tests the contribution of banana intraspecific diversity on reducing yield losses. The study describes banana variety diversity and tests its productivity in Uganda, disaggregating its overall effect into direct and indirect effects, in order to find justification for the promotion of diversity production systems. A spatial index (Herfindahl index) that combines both diversity richness and diversity evenness is first used in the analysis. Measures of diversity are also disaggregated to determine which index (evenness or richness) contributes the most to reducing yield losses and hence should be promoted.

The study is carried out in two different agricultural zones in Uganda. One study site, Nakaseke, is in a low elevation area, while the other, Kabwohe, is in a high elevation area. These two study areas differ in elevation, pest pressure, and hence in production potential. Overall, the sample included 120 banana farmers, but missing cases reduced the sample to 119 used in the estimation.

The econometric estimation reveals interesting results on the contribution of banana diversity on reducing yield loss caused by biophysical pressures. Overall, results show that an increase in banana diversity has a significant abatement effect, with a potential of reducing banana yield loss. This is in agreement with the findings from most previous studies carried out on annual crops. It can be concluded that even with perennial crops where pests and diseases accumulate, diversity can still contribute significantly to abating yield loss. The study findings also indicate that the most important aspect of diversity for abating yield losses in bananas is evenness. This means that farmers ought to mix varieties in relatively equal proportions to attain maximum benefit of abating yield losses caused by biophysical pressures.

However, results also show that maintaining high banana diversity is associated with yield trade-offs. Controlling for its abatement effect, high banana diversity seems to directly reduce banana yield. This means that without biophysical pressures, specializing in a few varieties with a high-yielding genetic potential may increase returns to management and enhance efficiency in resource utilization. This is likely to be optimal for well-to-do farmers who have the ability to bear risks. This category of farmers constitute less than 10 percent of the total banana farmers in Uganda, and the social benefits of yield loss abatement on the rest of farms resulting from adoption of spatial diversity are likely to be great. Therefore, within the current banana production environment of limited abatement agents and high biotic stress, enhancing diversity appears to be an important option despite trade-offs.

Interspecific diversity is important in increasing banana yields, although it may not be important in reducing yield losses caused by biophysical pressures. This, however, requires a more elaborate study to confirm these findings, since this study concentrates more on intraspecific diversity. Education and experience are also important in increasing banana yields through their effect on enhancing technical efficiency of farmers.

6.2. Policy Implications

This study contributes important information for policy. Findings show that promoting banana diversity would contribute to reduction of yield losses caused by biophysical pressures. Hence, banana diversity should be supported in Uganda because of its importance in yield stabilization and hence risk management. This can be done by planting the newly introduced varieties with the local varieties to obtain more value from a diversity production system. The varieties should, however, be evenly mixed to obtain a better effect in abating the yield losses.

In addition to diversity, farmers in the higher elevations, where the production potential is high, could improve their yields through increased intensification of labor inputs to implement good management practices. However, this strategy does not seem viable in the low elevation areas of the central part of Uganda, where adoption of labor-intensive management practices may be limited by low access to both family and hired labor for farming. Hence, options that are labor saving such as diversity should be explored further and encouraged in this region. Human capital development aspects such as education and extension services should also be encouraged as these enhance technical efficiency to obtain high yields in bananas.

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